RADC-TR-61-251

25 October 1961
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DEMULTIPLEXER-MULTIPLEXER

TD- ( )/GSC

Electro-Mechanical Research, Inc.
Advanced Systems Department
Sarasota, Florida

Contract Number: AF 30(602)2357

Prepared
for
Rome Air Development Center
Air Research and Development Command
United States Air Force

Griffiss Air Force Base
New York

NOX

RADC-TR-61-251 October 25, 1961

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ABSTRACT

This report presents the results of work performed since the completion of the engineering investigation, Item 1, Exhibit A, of Contract AF 30(602)2357. This contract calls for the development of a three-channel speech-processing equipment capable of transmitting and receiving three telephone messages simultaneously. The goal of simultaneous transmission of three voices over a single speech channel is accomplished through speech reiteration principles.

The work of the engineering investigation established the validity of the concept, optimum parameters, and circuit techniques. The assembly and test of the developmental models demonstrated the capability of the concept as a system. This report concludes all work on the referenced contract and is in compliance with Item 5 of Exhibit A.

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LIST OF ILLUSTRATIONS

SECTION 1. INTRODUCTION

This report is written in compliance with Item 5, Exhibit A, of Contract AF 30(602)2357. It represents the conclusion of all work under this Contract and supplements the technical content of the Technical Note RADC-TN-61-90, dated 1 June 1961. The Technical Note reported the results of the engineering investigation and the design concepts for the developmental models required by Item 3 of the referenced Exhibit A. This report presents changes in concepts brought about through system integration of the developmental models. It also presents the problem areas in which further work must be done to develop an optimized system.

It is assumed that, in general, those reading this report are familiar with the program conducted under this contract and with the principles of reiterated speech. Those who are not, should familiarize themselves with the Technical Note referenced above. It is the major technical document of this program and also contains an Appendix which explains in simple and concise form the principles of reiterated speech.

The major goal of this program was the development of a practical technique for implementing a system for the simultaneous transmission of three telephone conversations over a single telephone line using reiterated speech principles. An initial investigation was conducted by EMR to verify these principles in which the acoustic delay properties of air were used to obtain the long delays (milliseconds) required. Subsequent to this experiment, an engineering investigation was conducted to develop circuits required to accomplish synchronization, signaling, commutation and decommutation, and reiteration. Wire sonic delay lines were used in this investigation. These circuits were assembled into a skeletal system in which various techniques for improvement of reiterated speech quality were investigated. Following this program the Technical Note was written and work was started on the developmental models. Integration of the circuits designed in the engineering investigation into a complete system represented by the two developmental models resulted in some additional design work to overcome problems not readily predictable from previous work. When the quality of the developmental models was consistent with that of the skeletal system of the engineering investigation they were shipped to RADC.

The completion of developmental models provides a system developed to a degree satisfactory for further laboratory experiment. It demonstrates that three messages can be handled simultaneously, in conjunction with signaling and synchronization functions, using the reiterated speech concept. However, it also demonstrates that much work can and should be done to achieve the optimum system. Such areas as synchronization, spectral shaping, and delay distortion effects are those in which further work will pay dividends in system performance.

SECTION 2. DISCUSSION

The purpose of this section is to discuss the technical program conducted under Contract AF 30(602)2357 since the completion of the engineering investigation through the completion of the developmental models. Technical Note RADC-TN-61-90 reported the results of the program through the completion of the engineering investigation. The work since that report has consisted of construction, system assembly, and test of the developmental models of the Demultiplexer-Multiplexer equipment. Therefore, this report presents changes in concepts brought about by system integration and also discusses performance of the completed equipment.

2.1 Summary of Previous Work

The work of the engineering investigation phase, as previously reported, consisted mainly of design, analysis, and test of the circuits for the basic blocks of the conceived system. The block diagram, Figure 1, illustrates the final system concept represented by the completed developmental models.

Feasibility of the techniques chosen to implement the system was proved on a subsystem basis. The synchronization system, the signaling system, the hybriding techniques, and the reiteration techniques were the major subsystems developed during the engineering investigation. However, complete system integration could not be accomplished until two complete models were constructed. The major portion of the engineering investigation focused on the reiteration techniques and methods of removing distortion introduced through processing. A "one-way" skeletal system was implemented for this purpose. This system consisted of a three-channel electronic commutator with appropriate amplifiers, a three-channel decommutator, the reiteration delay system, and provisions for inserting various filters and shaping networks. No hybrids were required since transmission was unidirectional. Various filtering techniques, including an elementary comb filter were studied experimentally to determine their ability to reduce the objectional characteristics introduced by processing.

2.2 Fabrication of Developmental Models

One of the major advantages of the reiterated speech concept is its inherently small package size compared to more complex systems designed to accomplish the same purpose. No extreme effort has been exerted during this program to miniaturize this equipment other than complete transistorization. Even so, the developmental models were packaged into an 8-3/4" x 19" x 18" space, including power supplies. Plug-in card construction was used throughout with the exception of the power supplies. These were constructed on a main chassis. Potted filter packages and all connectors were also mounted on this chassis. In all, the developmental models are broken down into four major subassemblies. These are the main chassis, the card file, the delay line package, and the front panel. Interconnections between these units are made at the main chassis.

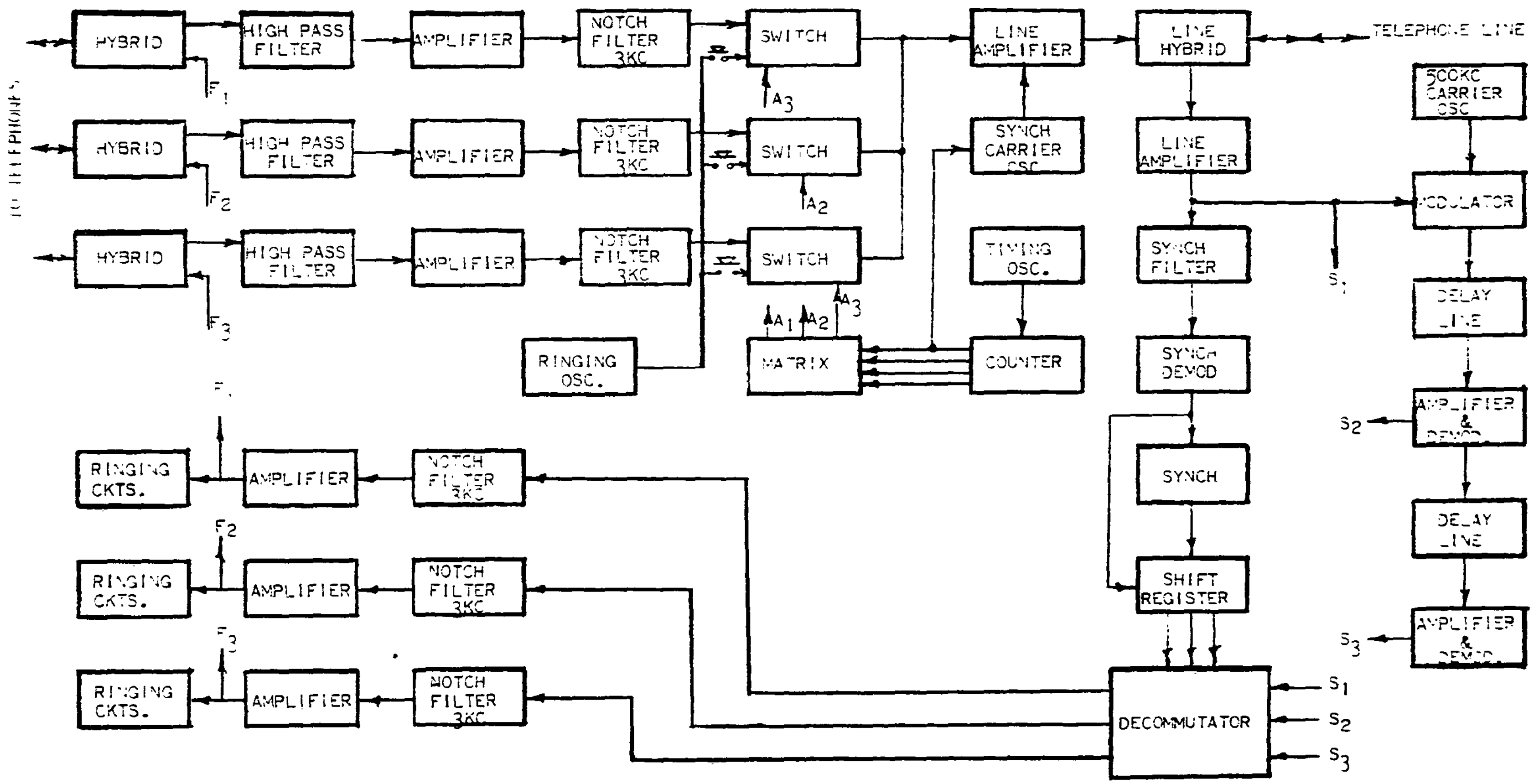


FIG. 1 - DEMULTIPLEXER-MULTIPLEXER TD- ( ) /GSC

The plug-in cards and the card file are commercially available. The plastic guides used in this equipment deteriorated badly. However, a later model of the card file provides a more satisfactory mounting technique for the guides. Figure 2 is a picture of the front and back of a typical board with components in place and wired. Since the system is a three-channel system, it was convenient to arrange circuits so that certain boards were duplicated in a complete unit. For instance, the input hybrid, associated amplifiers, and one transistor switch (part of the commutator) required for one channel are assembled on one board as shown in the circuit schematic of Figure 3. Three of these boards are interchangeable with each other. The decommutator sections, ringing filter and ringing indicator circuits for one channel are also constructed on a single board. Three of these per unit are also required.

Printed w ring was not used in the developmental models for two reasons:

1) The system is basically experimental and, as such, required considerable flexibility to make circuit changes up to the very completion of the developmental models.

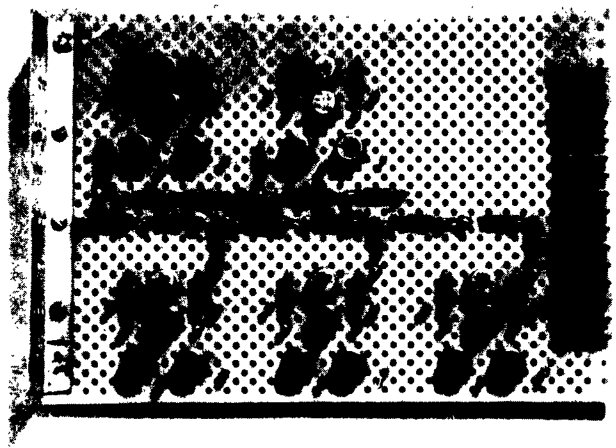
2) There were not sufficient numbers of like boards being constructed to justify the preparation of such boards on an economic basis.

However, the plug-board construction used in this equipment simplifies the work required to design printed wiring boards because the circuits are now divided into logical units and are packaged within the amount of space which would be available on a standard printed-circuit card.

Some filters were potted rather than mounted on plug-boards because it was necessary to wind toroidal inductors and to parallel selected capacitors to obtain the required filter characteristics. Potting these components assures that the filters are tamper-proof and presents a neater appearance as opposed to the equivalent layout on a plug-board. Simple filters, such as the bridged-T notch filters, were constructed on the boards with the circuits with which they were used. In this case, the toroidal inductors were small and were potted as a single component.

Power transformers and chokes were also of EMR design and construction. This was done primarily to obtain more exactly the characteristics desired and secondarily for appearance and size considerations.

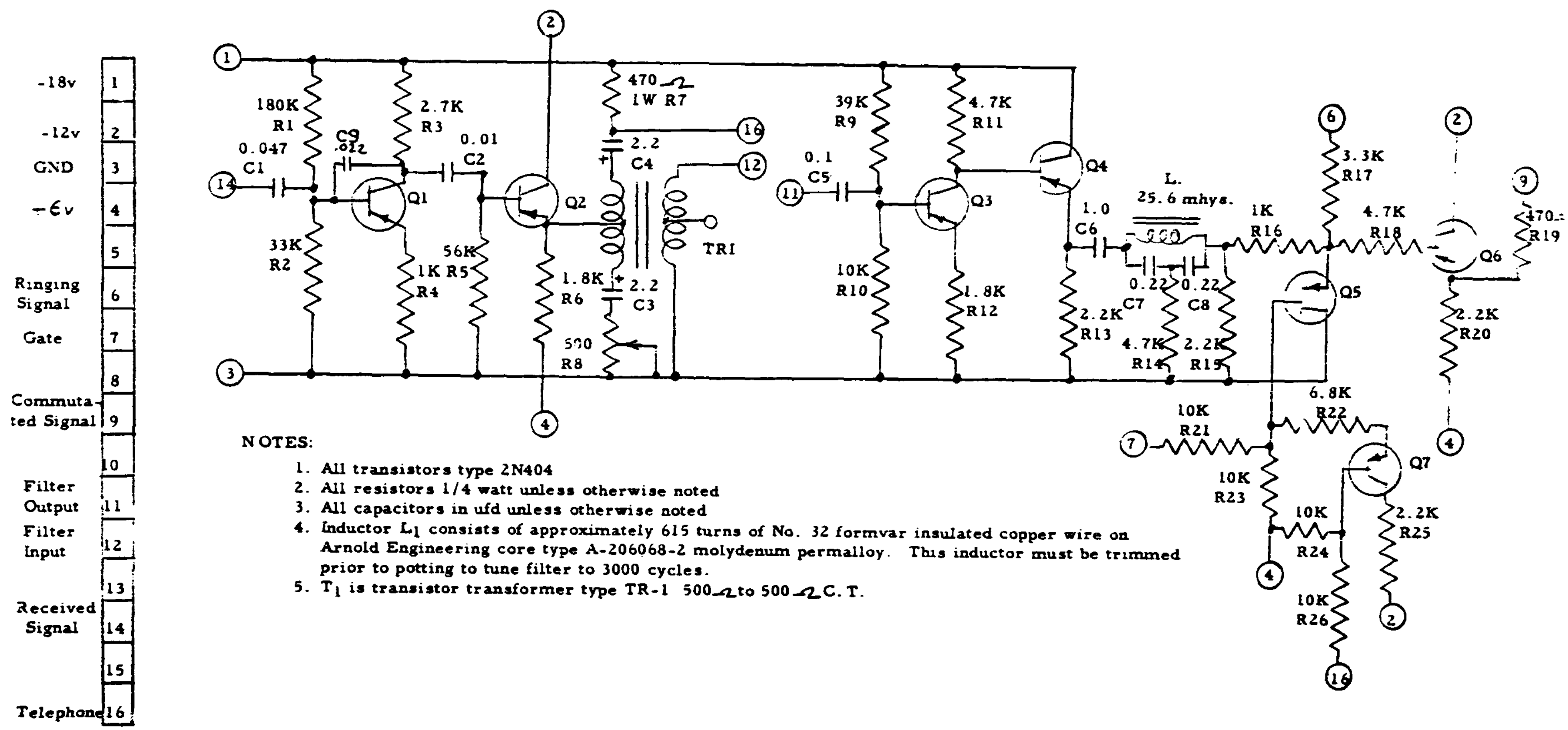
The completed unit is mountable in a standard 19-inch relay rack. It requires a space 8-3/4 inches high. The picture, Figure 4, shows the front view and top view of one of the completed units.



FRONT

BACK

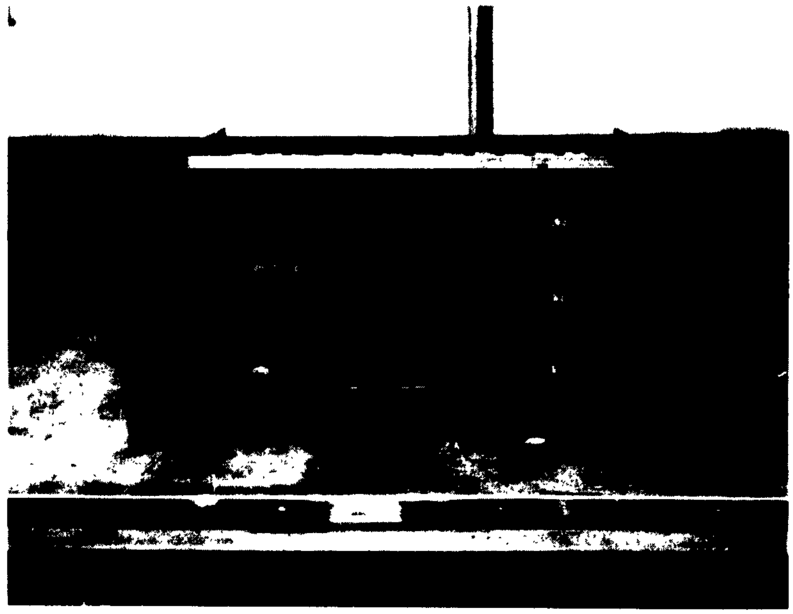
FIG. 2. TYPICAL CIRCUIT CARD



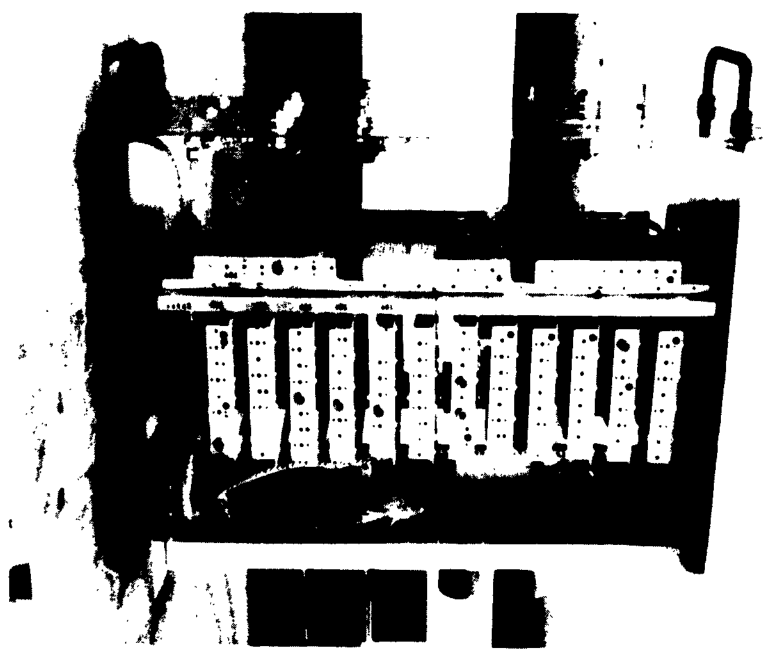
NOTES:

1. All transistors type 2N404
2. All resistors 1/4 watt unless otherwise noted
3. All capacitors in ufd unless otherwise noted
4. Inductor L_1 consists of approximately 615 turns of No. 32 formvar insulated copper wire on Arnold Engineering core type A-206068-2 molydenum permalloy. This inductor must be trimmed prior to potting to tune filter to 3000 cycles.
5. T_1 is transistor transformer type TR-1 500Ω to 500Ω C.T.

FIG. 3 HYBRID AND COMMUTATOR CARD



FRONT VIEW



TOP VIEW

FIG. 4. DEVELOPMENTAL MODELS
DEMULTIPLEXER-MULTIPLEXER TD- ( )/GSC

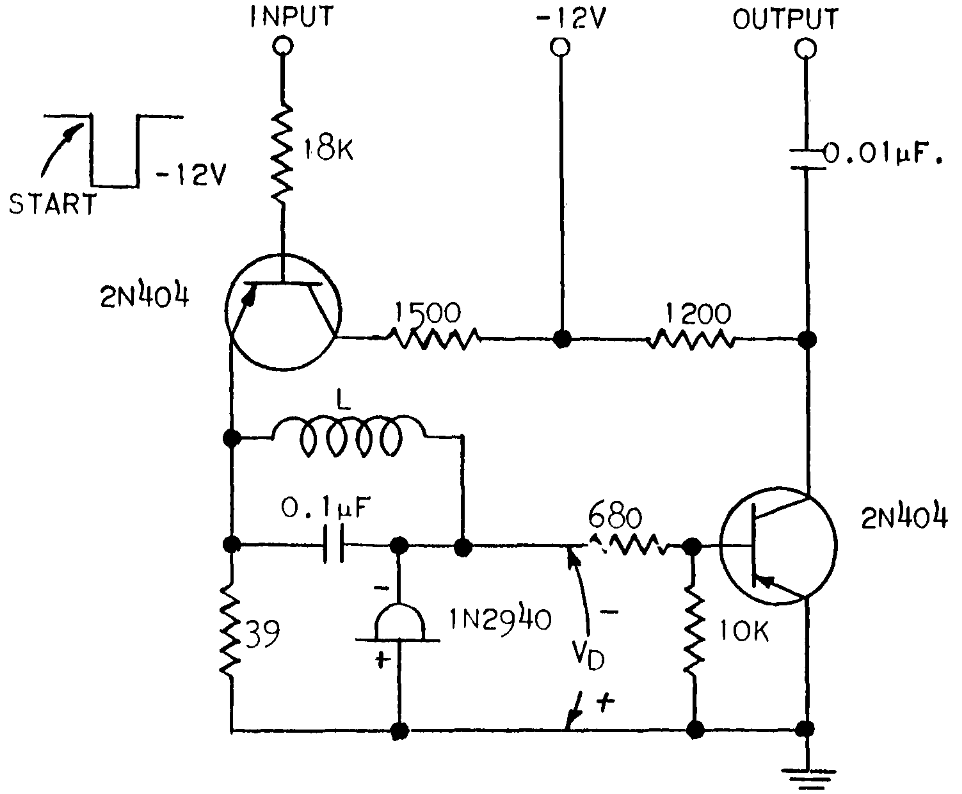
2.3 System Integration

2.3.1 Circuit Considerations

On completion of the engineering investigation, work was begun on construction of the circuit boards required for the developmental model. Each one was tested as it was finished, to determine that it was functioning properly. During the course of this construction and testing phase, only one major design change was required because of improper circuit operation. The circuit shown in Figure 5 is the synchronization carrier oscillator whose operation was explained in the Technical Note. While it had been breadboarded during the engineering investigation, it was not discovered that small changes in temperature at the tunnel diode resulted in prohibitive frequency drift. Therefore, it was necessary to redesign this circuit. The tunnel diode was eliminated and the circuit shown in Figure 6 resulted. In this circuit, the series LC combination is the primary frequency determining network. Some adjustment can be obtained by adjusting the feedback potentiometer. This circuit is designed to operate at precisely 3000 cycles. It is gated on and off by the transistor in series with the LC circuit. During normal operation, this circuit will produce a 21-cycle (seven milliseconds) sinusoidal burst every 21 milliseconds as determined by the timing oscillator and counter.

The sync detector and filter circuits were not developed during the engineering investigation. They evolved during the system integration phase of the program since their required characteristics were not known explicitly. Figure 7 illustrates the final circuit which was incorporated in the developmental models. The filter portion of the circuit is comprised of the two transistors Q_1 and Q_2 arranged as a feedback amplifier in conjunction with a notch network to provide a sharply tuned amplifier. The signal from this amplifier is rectified, filtered and converted to a rectangular waveform. This waveform is the reset signal to the shift register and the gate to phase-locked loop which comprises the synchronizer. (Refer to RADC-TN-61-90 for a discussion of the synchronizer concept.) A unique feature of the filter portion of the circuit is the notch network. The resistor, R_x, is the only variable required to vary the notch frequency. Its value should be kept within ±50 percent of the value of the other two resistors, R_4 and R_6, to assure a good notch. The capacitor C_4 should be approximately one-twelfth the value of the other two capacitors C_3 and C_5. A variation of ±50 percent in R_x results in a frequency change ratio of about 1.5 from the lowest to the highest frequency. The sharpness of the filter is determined by the amount of regenerative feedback and is adjusted by selecting R_y. Of course, too much regenerative feedback results in oscillation.

Modifications were required to the input hybrid circuits to adjust the signal levels so that the incoming signal was audible in the telephone receiver, yet was not sufficient to cause oscillation in the hybrid. These modifications consisted of adding amplifiers to the input and output of the hybrid. Figure 3 is the schematic of a hybrid with the added amplifiers and one section of the commutator. As mentioned previously, three of these boards are required for each



THE INDUCTOR L IS WOUND ON A TOROID. THE VALUE IS DETERMINED BY TEST TO GIVE AN OUTPUT AT 2900 CY.

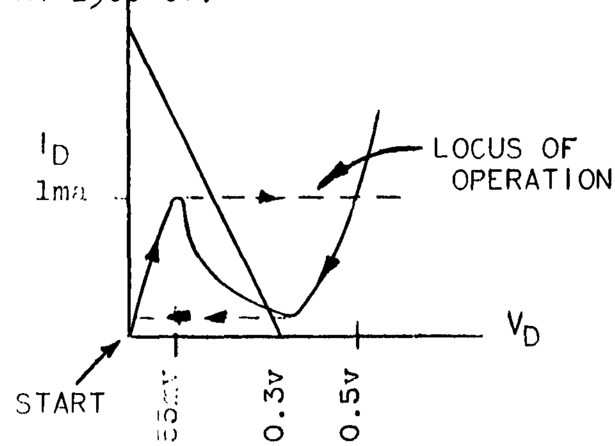


FIG. 5. SYNC. CARRIER OSCILLATOR

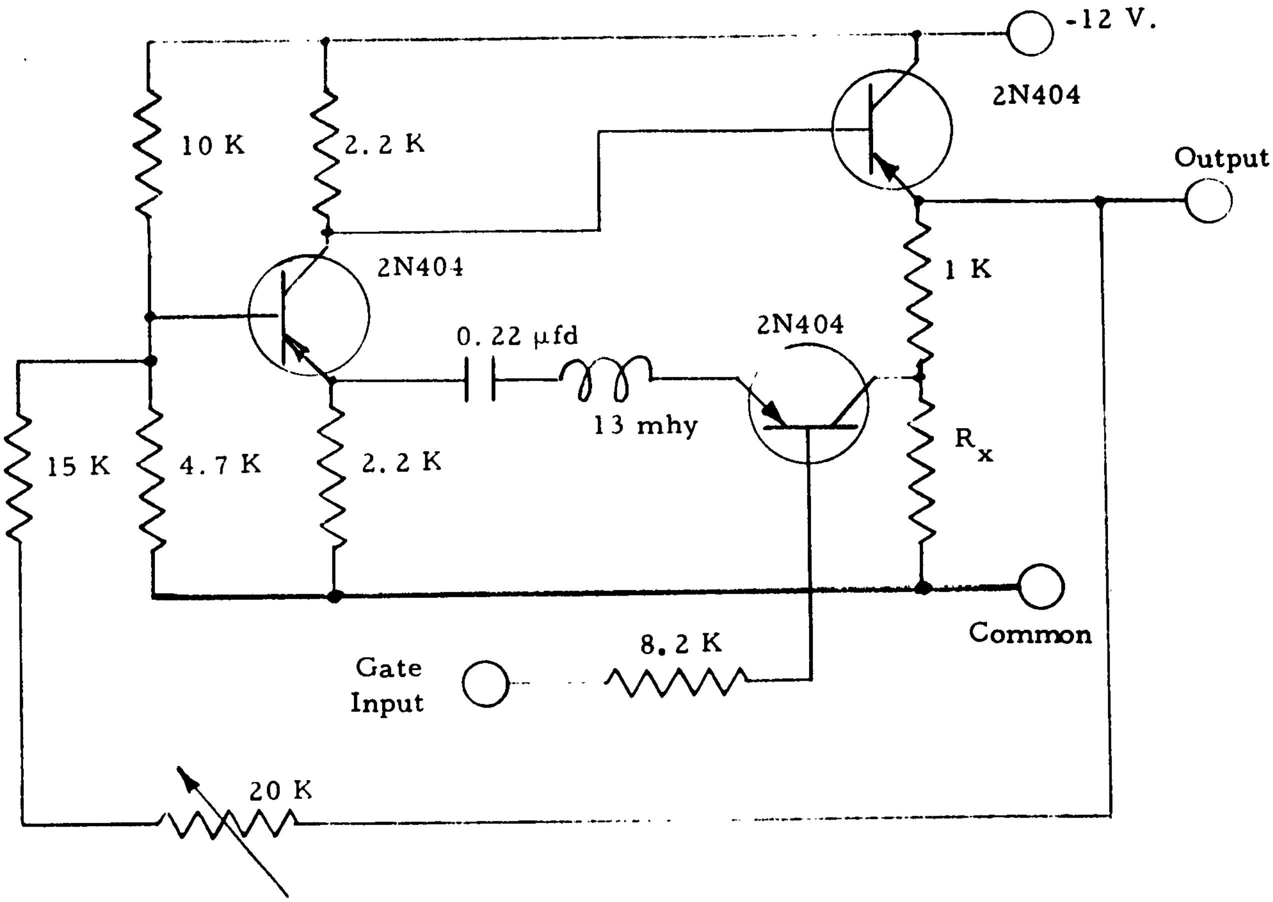
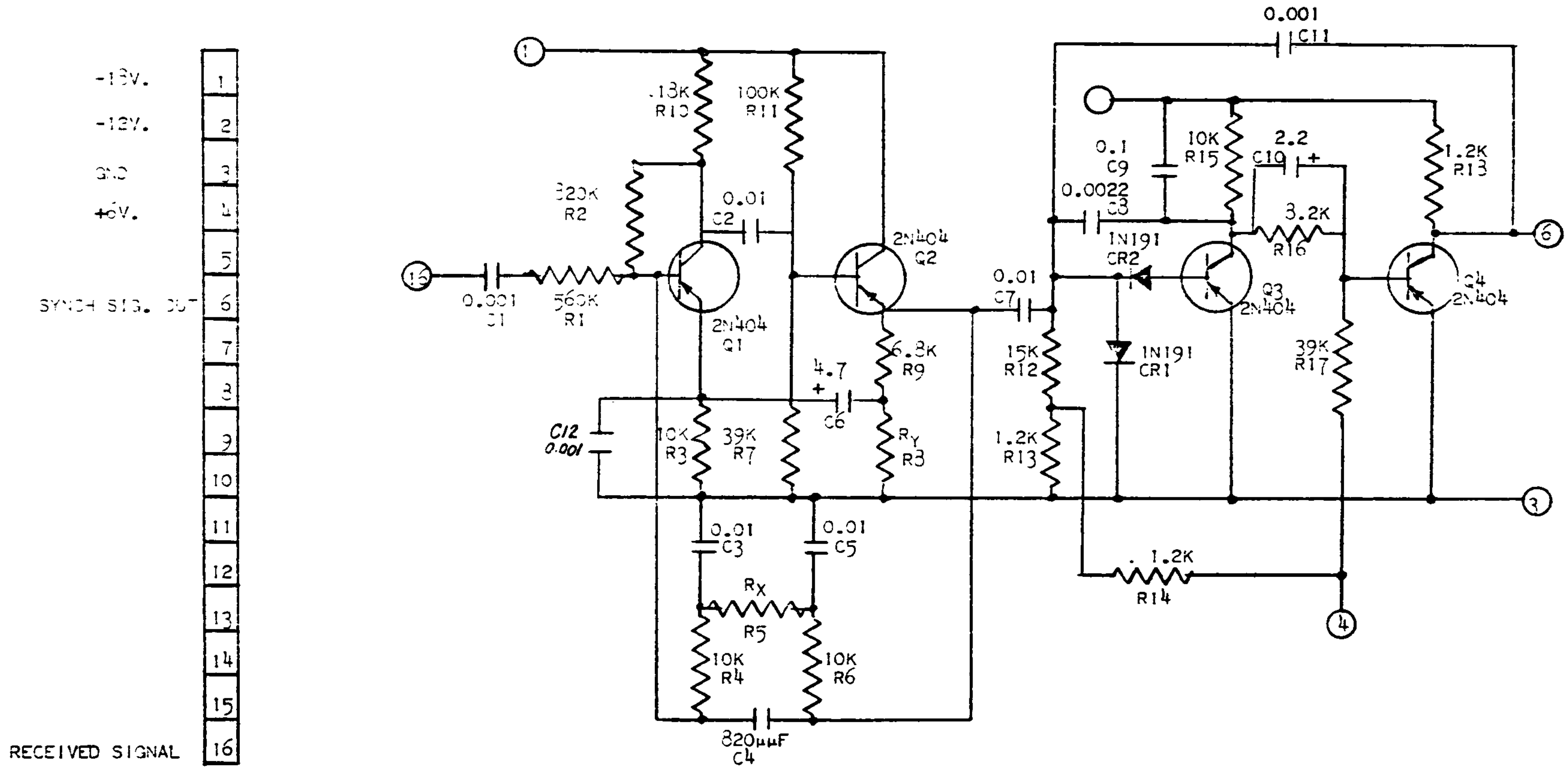


FIG. 6 IMPROVED SYNC CARRIER OSCILLATOR



NOTE: 1. R_X & R_Y ARE TEST VARIABLES. R_X IS IN THE NEIGHBORHOOD OF 10K OHMS & R_Y 560 OHMS
R_X TUNES FILTER TO 3000 CYCLES.
2. ALL CAPACITORS IN μF. UNLESS OTHERWISE NOTED
3. ALL RESISTORS 1/4 WATT UNLESS OTHERWISE NOTED

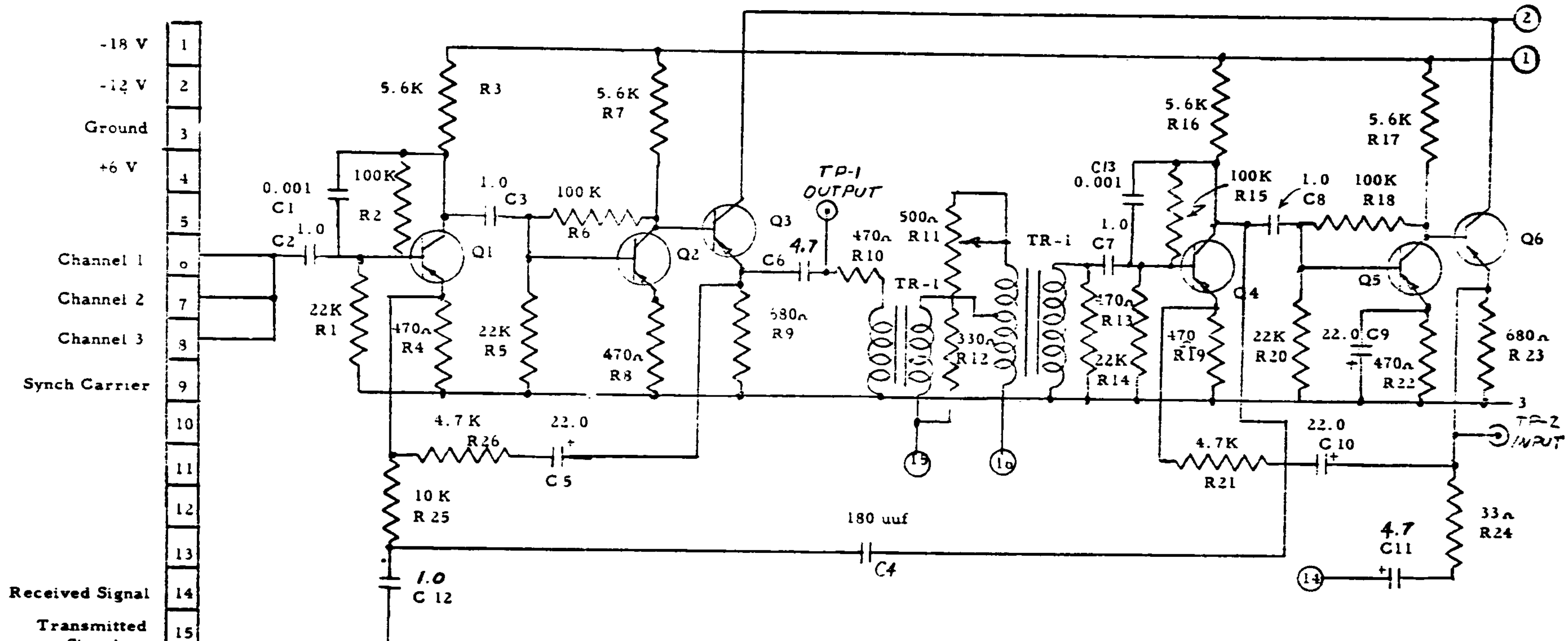
FIG. 7 SYNC FILTER AND DETECTOR

complete unit. Because of the size of the components, the 300 cycle per second high-pass filters shown on the block diagram of Figure 1 were mounted on the main chassis. They connect to the terminals numbered 11 and 12 via the plug-board connector. A bridged-T filter is included in the circuit to remove any 3000-cycle component from the voice prior to commutation. This is necessary because the sync carrier frequency is also at 3000 cycles and any voice components in this region will cause spurious responses in the sync system. Another feature added to reduce the likelihood of excessive coupling between the hybrid input and output resulting from circuit unbalance, when the phone is out of the circuit, is the transistor switch Q_7. This switch blocks the output when the phone is not energized. This coupling could conceivably cause oscillation in the system if permitted to exist.

The line amplifiers and hybrids produced some problems which were readily corrected without extensive modification of the circuits presented previously in the Technical Note. The major problems were the tendency toward oscillation and coupling through the hybrid from the output side to the input. The first problem was corrected by proper gain selection and proper matching of the hybrid transformer. The 470 ohm resistors R_{10} and R_{13} in Figure 8 were added to achieve the proper match. The problem of coupling through the hybrid produced difficulty, primarily in the sync loop because of the high gain of the sync filter circuit. A small portion of the transmitted sync carrier coupled through and caused the synchronizer to break "lock" with the incoming sync signal. This was corrected by feeding a portion of the outgoing sync carrier out of phase into the input side of the hybrid, thus cancelling the portion coupled through the hybrid. Capacitor C_4 of Figure 8 performs this function.

The basic concept of the synchronizer, Figure 9, remains unchanged. Some component values and some connections were changed over the circuit given in the Technical Note. The circuit values were changed to obtain the optimum delay time and proper gate amplitudes for the discriminator. Otherwise, the circuit remains the same and functions are as described in the Technical Note.

The decommutator and ringing circuits remain basically unchanged from the original configuration. Figure 10 is the schematic drawing of these circuits. Some component values have been changed to enhance the performance of the circuit. A bridged-T filter has been added to the output of the decommutator to remove the 3000-cycle sync carrier. This signal cannot be removed prior to decommutation as originally planned because decay times for low-pass filters capable of passing up to 2800 cycles while attenuating 3000 cycles are sufficiently long so as to cause crosstalk between channels. This results from the fact that the information coming into such a filter comprises the three transmitted samples of the three input channels rather than a single message. The bridged-T filter is included on all boards although it is required only in the channel in which the sync carrier appears. Including a filter on all boards makes boards interchangeable. An emitter follower is required also to match the filter to the decommutator.



NOTES:

1. All Transistors are Type 2N404
2. All capacitance values are in uf. unless otherwise noted.
3. All resistors are 1/4 watt unless otherwise noted.

FIG. 8 LINE AMPLIFIERS AND HYBRID

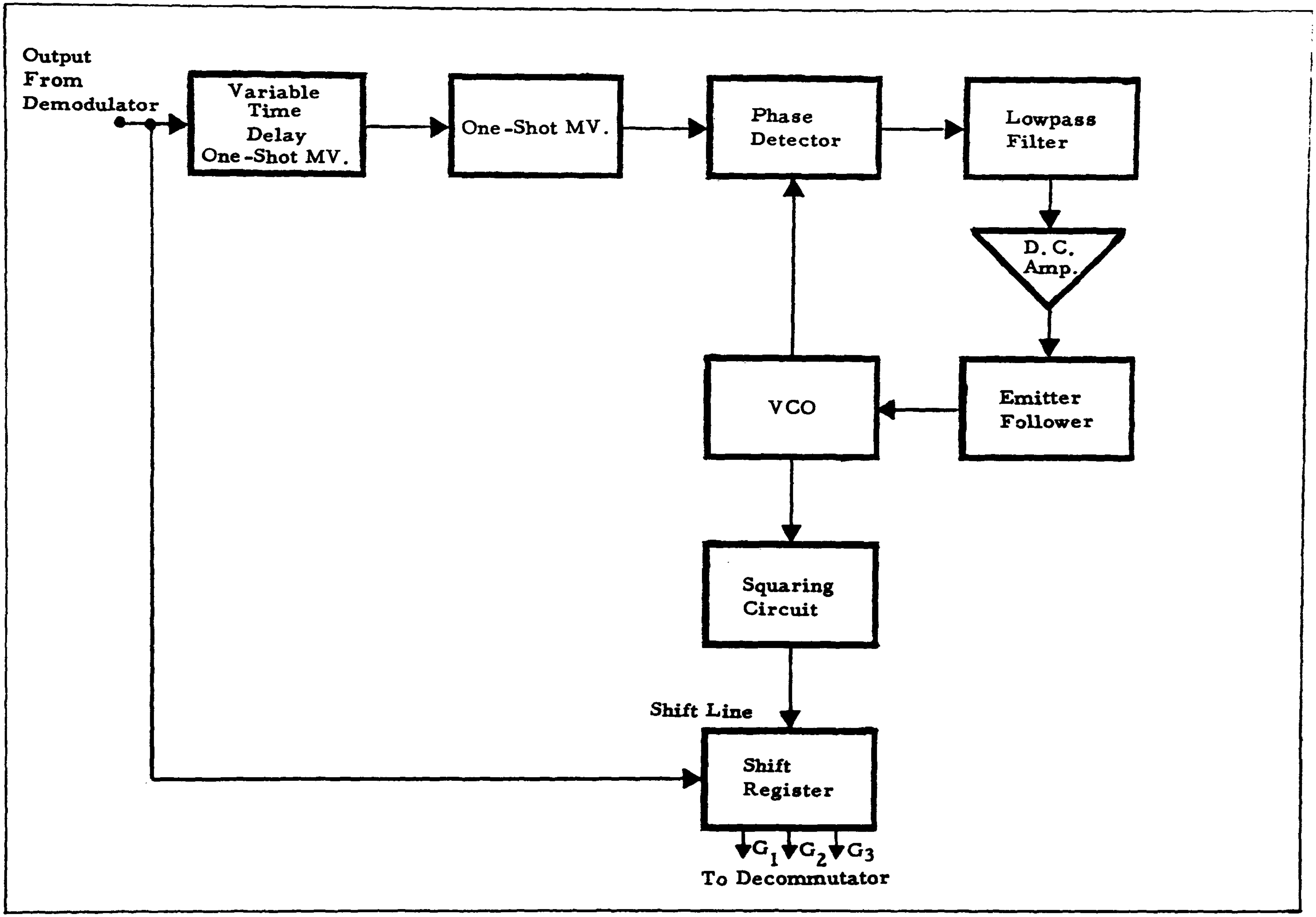


FIG. 9. SYNCHRONIZER BLOCK DIAGRAM

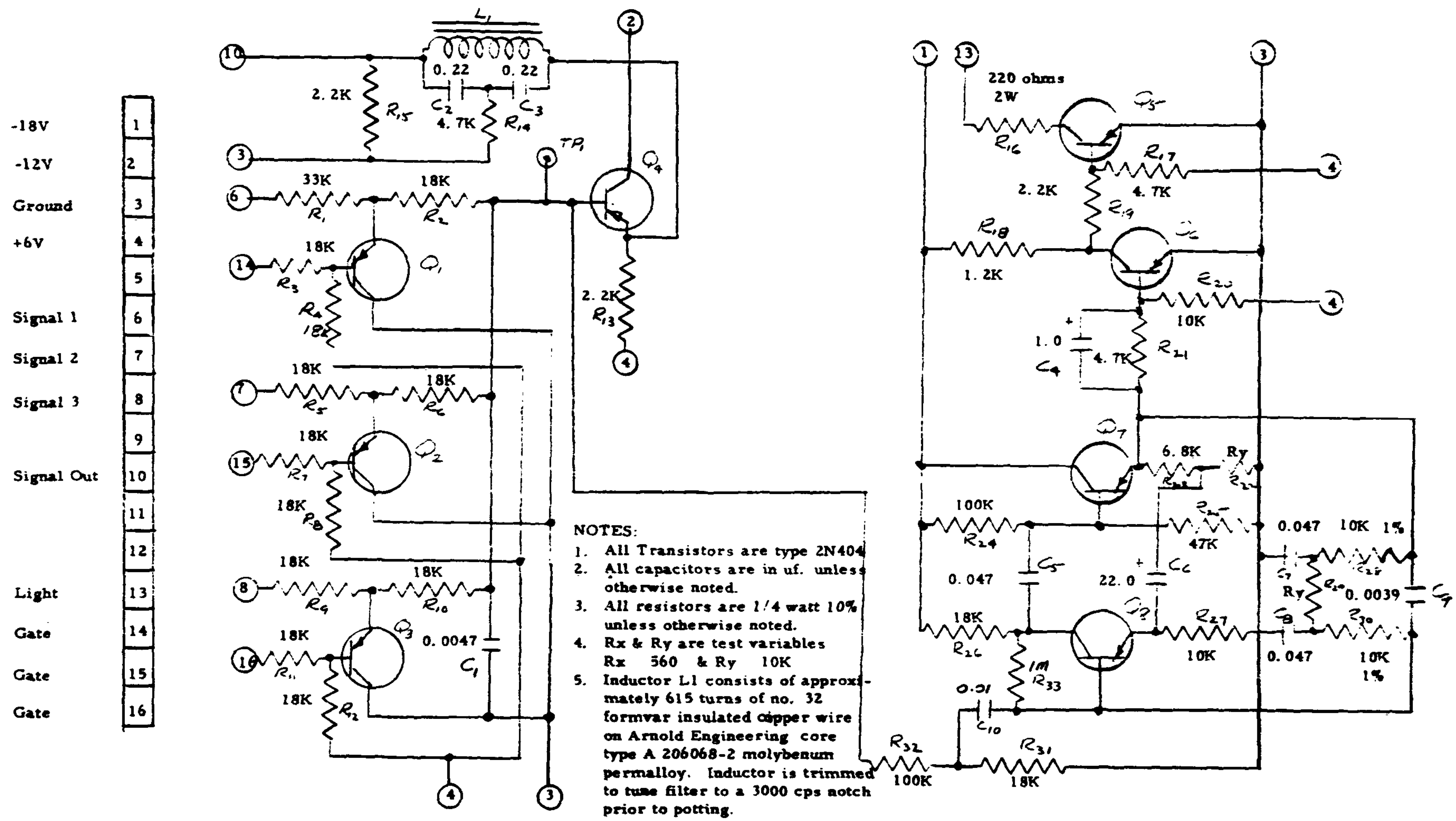


FIG. 10 DECOMMUTATOR AND RINGING CIRCUITS

The ringing circuits tended to oscillate because of the high gain in the ringing filter circuit. The amount of regenerative feedback was reduced by adjusting R_y in Figure 10. Also, the transistor Q_5 tended to stay on once triggered. The resistor R_{17} was added to bias this transistor off when no input signal was present.

In the Technical Note it was mentioned that the output circuit of the wire sonic delay lines would be modified to provide for more stable and efficient operation. The input circuit was also modified slightly. An emitter follower was used previously to drive the delay line, but the particular configuration used was of marginal design. Figure 11 shows the present configuration of the 500-kc oscillator and modulator. The delay line is now driven directly by the modulator output transformer. The output circuit of the delay line was modified by tapping down 10:1 on the toroidal inductor supplied by the manufacturer to obtain a 100:1 reduction in output impedance. This inductor is located inside the delay line package. A trimmer capacitor is also located in this package. The equivalent circuit for the delay line is shown in Figure 12. Tapping down on this inductor resulted in a 10:1 decrease in output voltage, but permitted a more optimum transistor amplifier design than was previously possible. This amplifier is shown along with the detector circuit in Figure 13. Variation in characteristics from delay line to delay line requires that each amplifier be matched to a particular line to equalize the output voltage levels.

The power supply has only minor changes from the earlier version to accommodate available components.

All other circuits, counter, shift register, timing oscillator, etc., either remain unchanged or have had only minor component value changes.

2.3.2 System Testing

Testing of the two developmental models as a complete system was the final step in completing the program. Many problems which were not easily predictable previously, now became apparent. The majority of these problems occurred in and because of the synchronization system. These problems were remedied in the two models delivered to RADC, however, not to the complete satisfaction of EMR. It is now believed that a better approach to the synchronization problem is possible. Some of the lesser problems were inadequate amplification, proper division of amplification between the input and the output of the input hybrids, oscillations because of improperly terminated hybrids, and oscillation in the ringing indicator circuit. These problems were corrected, as discussed in the previous section.

The major problem in the synchronization system was the close proximity of the sync carrier frequency (3000 cycles per second) to the voice band (300 to 2800 cycles per second). When EMR began work on this Contract, the allotted bandwidth was to be 300 to 4000 cycles per second. It was intended in the early stages of the program to cut off the voice band at 3200 cycles per second and

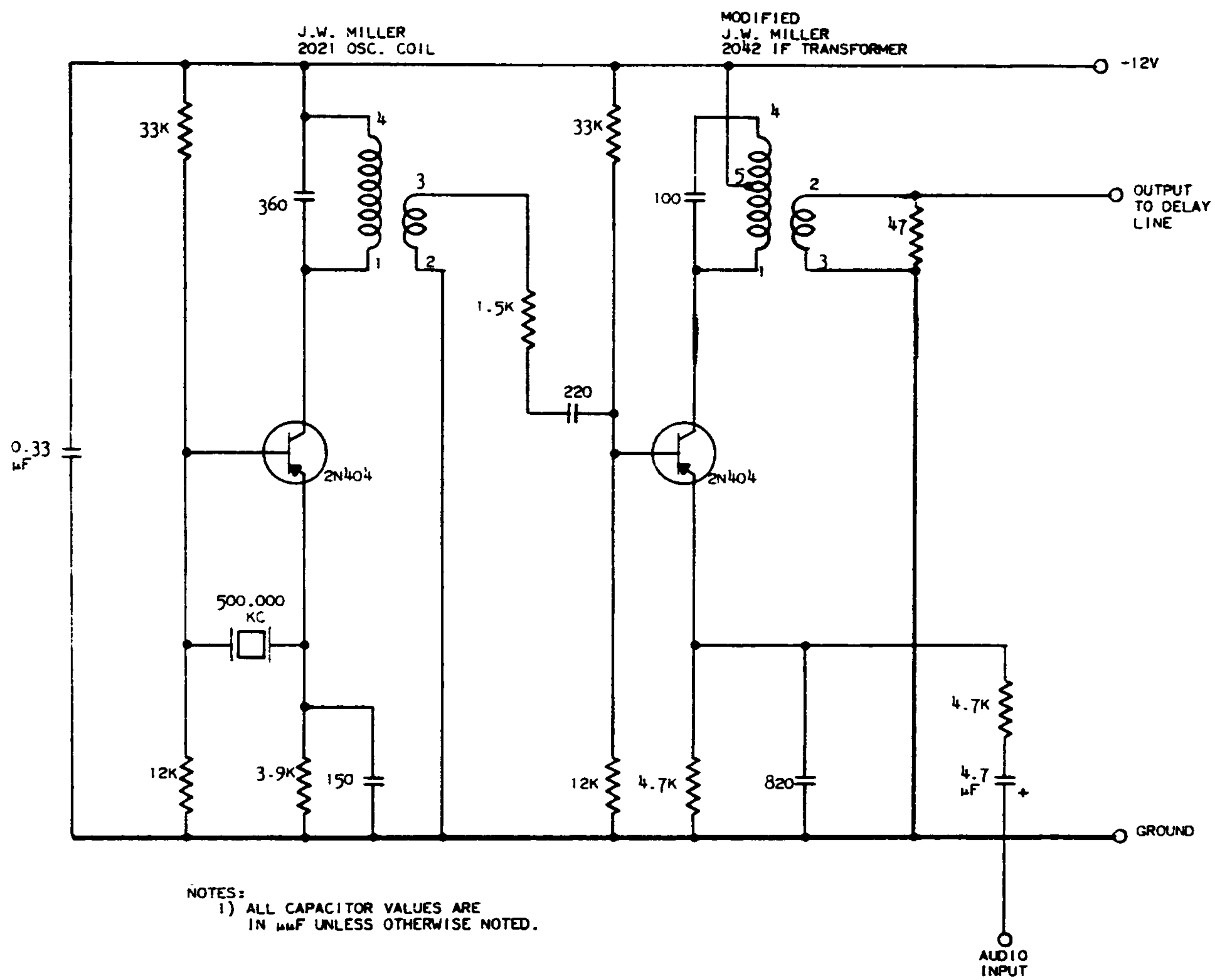


FIG. 11 500KC OSCILLATOR-MODULATOR

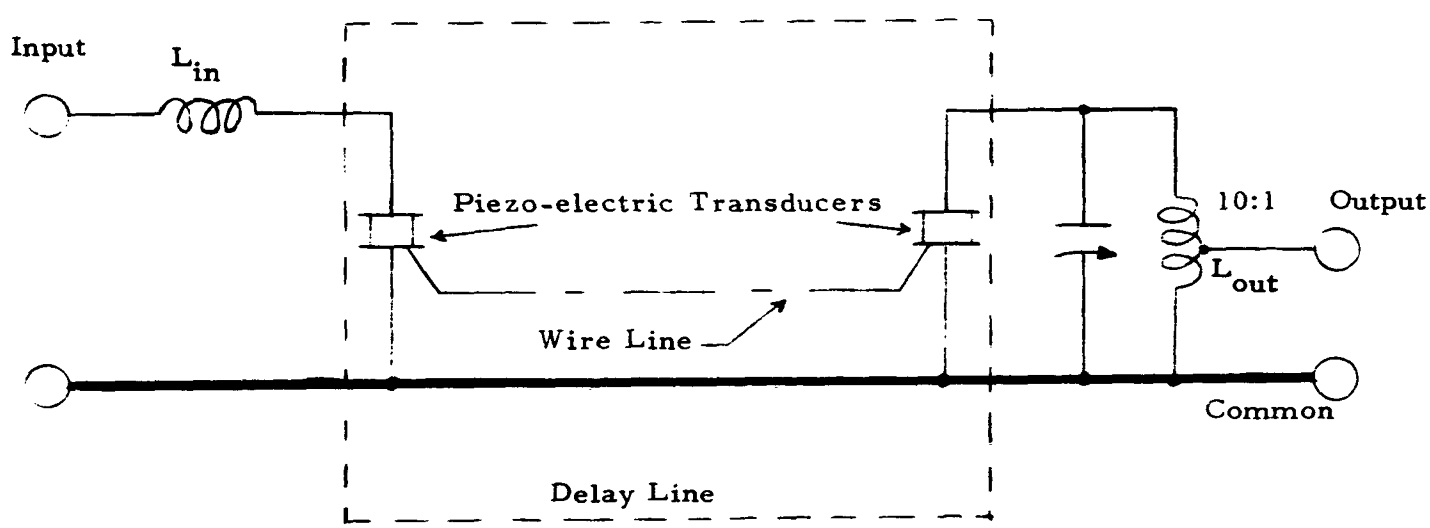
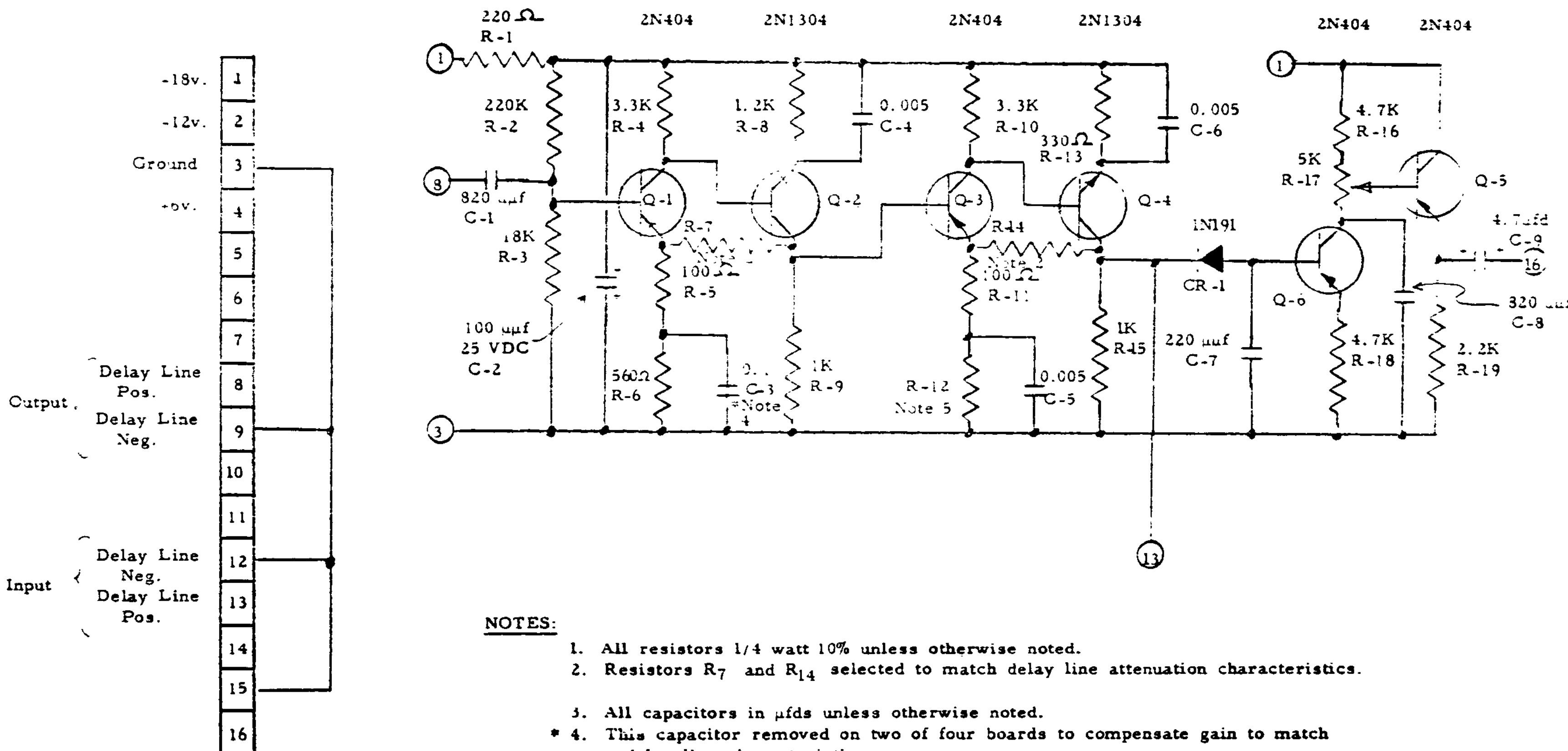


FIG. 12 EQUIVALENT CIRCUIT OF WIRE SONIC DELAY LINE



NOTES:

1. All resistors 1/4 watt 10% unless otherwise noted.
2. Resistors R_7 and R_{14} selected to match delay line attenuation characteristics.

3. All capacitors in μfds unless otherwise noted.

* 4. This capacitor removed on two of four boards to compensate gain to match delay line characteristics.

5. R-12 selected to adjust bias on detector and must be selected in accordance with R-14

FIG. 13 DELAY LINE AMPLIFIER AND DEMODULATOR

locate the sync carrier in the region between 3800 and 4000 cycles per second. Practical considerations, namely, the bandwidth of commonly available telephone lines, resulted in reduction of the specified bandwidth to 300 to 3000 cycles per second by verbal agreement with RADC.

The close proximity of the sync carrier to the voice band made it difficult to eliminate voice signals at the sync carrier frequency. The occurrence of the extraneous signals in the sync system causes the sync to "bounce" thus resulting in noise due to cross-coupling between channels. The sync carrier is required to be transmitted with the voice signal and subsequently must be separated at the receiving end. Adequate separation for the previously stated frequency conditions requires that the sync filter be narrow band, yet a narrow band filter adequate to reject the voice has buildup and decay times that are prohibitive. Therefore, it was necessary to compromise to achieve a workable system under these circumstances. One of the areas of compromise was the sync filter. Its bandwidth was permitted to be approximately 160 cycles per second between the half-power points. The lower half-power point on the bridged-T filters prior to the commutator was set at 2800 cycles and the upper at 3200 cycles. Attenuation in the notch at 3000 cycles was of the order of 40 to 50 db. The overlap in these two filters, however, is still sufficient to allow an appreciable amount of the voice band signal into the sync filter. Therefore, the sync carrier signal was given an amplitude advantage on mixing with the transmitted voice sample to reduce the interference with the sync channel. These techniques resulted in a partial solution, although not completely satisfactory, to the problem of separation of sync signals from the voice. It is possible in the present system to observe a "bounce" of plus or minus one cycle (one-third of a millisecond). This represents approximately a five percent timing error. This error results in "noise" being generated because of crossover into other channels.

The previous section discussed various circuit "fixes" designed to remove sync carrier components from the audio reaching the telephone. These "fixes", while effective, did not completely solve the synchronization problem. It is now recognized that the use of separate oscillators for timing, synchronization carrier, and ringing was responsible for many of the problems encountered.

A more optimum synchronization system would result by using a crystal-controlled oscillator operating at 3000 cycles per second or higher and counting down from there to the other frequencies required. Then the synchronization carrier burst would be obtained by gating a seven-millisecond sample of the 3000-cycle signal. This concept is illustrated in the block diagram of Figure 14. This technique would eliminate problems created by drift between the sync carrier frequency and the timing oscillator frequency. Side benefits are derived from using the 1000-cycle signal available from the counter for ringing and line test rather than the generation of a third frequency. Among these benefits are the use of a harmonically related and locked signal with respect to the chopping frequency and the elimination of an additional oscillator. These techniques, of course, do nothing about the basic problem--that of interference between sync carrier and audio.

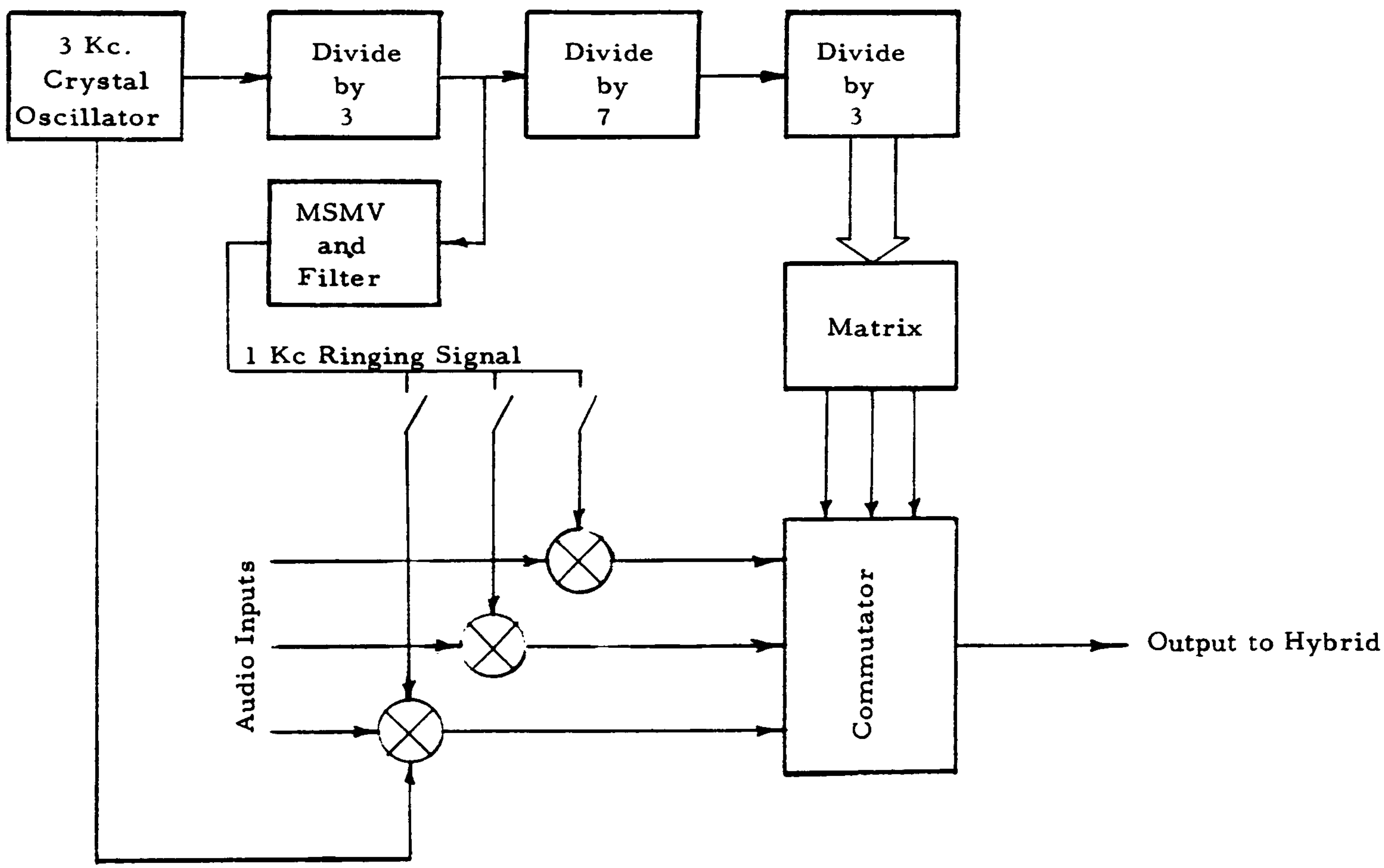


FIG. 14 IMPROVED SYNC GENERATION SYSTEM

A proposed technique to achieve better synchronization, overcoming the interference problem, is illustrated in Figure 15. This system provides a coarse and a fine error sensing system. It eliminates the need for a voltage-controlled oscillator and fixed-delay multivibrators and the need for adjustment if the propagation delay is changed. The input signal to this block diagram is the received signal output of the line hybrid of the system block diagram. In one of the three segments of this time-multiplexed signal there is the 3000 cycle burst of sync carrier signal plus audio as in the developmental models. At the transmitting end, the audio is amplitude limited and is always less than the sync carrier amplitude. At the receiving end the signal, as before, is delayed twice by the seven-millisecond delay networks. However, prior to decommutation the three inputs to the decommutator are summed and filtered by a narrow band 3000 cycle filter. This filter acts as an electronic "fly wheel" in that it will have long rise and decay times. If signal is suddenly applied or removed no immediate change in output will be observed. Once the equipment is turned on and the filter output has built up, occasional loss of a sync carrier burst would not be noticed by the filter. Its output frequency is divided by 21 in a flip-flop counter chain. The output of this frequency divider is used to drive a delay multivibrator whose delay is controlled by the COARSE and FINE error signals. A manual adjustment may also be provided to compensate for basic system errors. This delay will be of the order of seven milliseconds and will be varied either side of this figure by the error signals. The output frequency of this delay is divided by three and this divider drives a matrix which, in turn, provides the three sequential seven-millisecond gates to drive the commutator. COARSE error information is obtained by an envelope detection technique but without the use of a bandpass filter. The signal from the hybrid is gated through an AND gate by the proper channel gate from the matrix. A threshold is established and the sync plus audio peaks are detected. (The sync will be larger than the audio in adjacent channels.) This envelope is detected and squared and subsequently compared to the other two channel gates. If an output is obtained from one AND gate, a LATE error will be indicated and a voltage will be produced which will compensate for the error by narrowing the delay multivibrator gate width. If an output is obtained from the other AND gate a voltage of opposite polarity is produced and widens the gate width to compensate for the EARLY error. It is anticipated that this technique alone will not produce the desired stability in the presence of audio. Therefore, a FINE error detection loop is provided to hold the delay to a fraction of the time for one cycle of 3000 cycles. This is done by comparing the 3000-cycle signal from the "fly wheel" filter to the reiterated 3000-cycle signal, filtered through a much wider bandpass filter in a phase discriminator. The output of this discriminator is added to the COARSE error signal. This sync system is more complex in concept than the one used in the developmental models but is less critical in adjustment and, consequently, more reliable. It is estimated that the increase in number of components over the earlier system is negligible. No voltage-controlled oscillator is used and the only monostable multivibrator used is in a controlled loop. An additional advantage is that once the system is adjusted to compensate for internal errors, it will automatically compensate for changes in propagation delay.

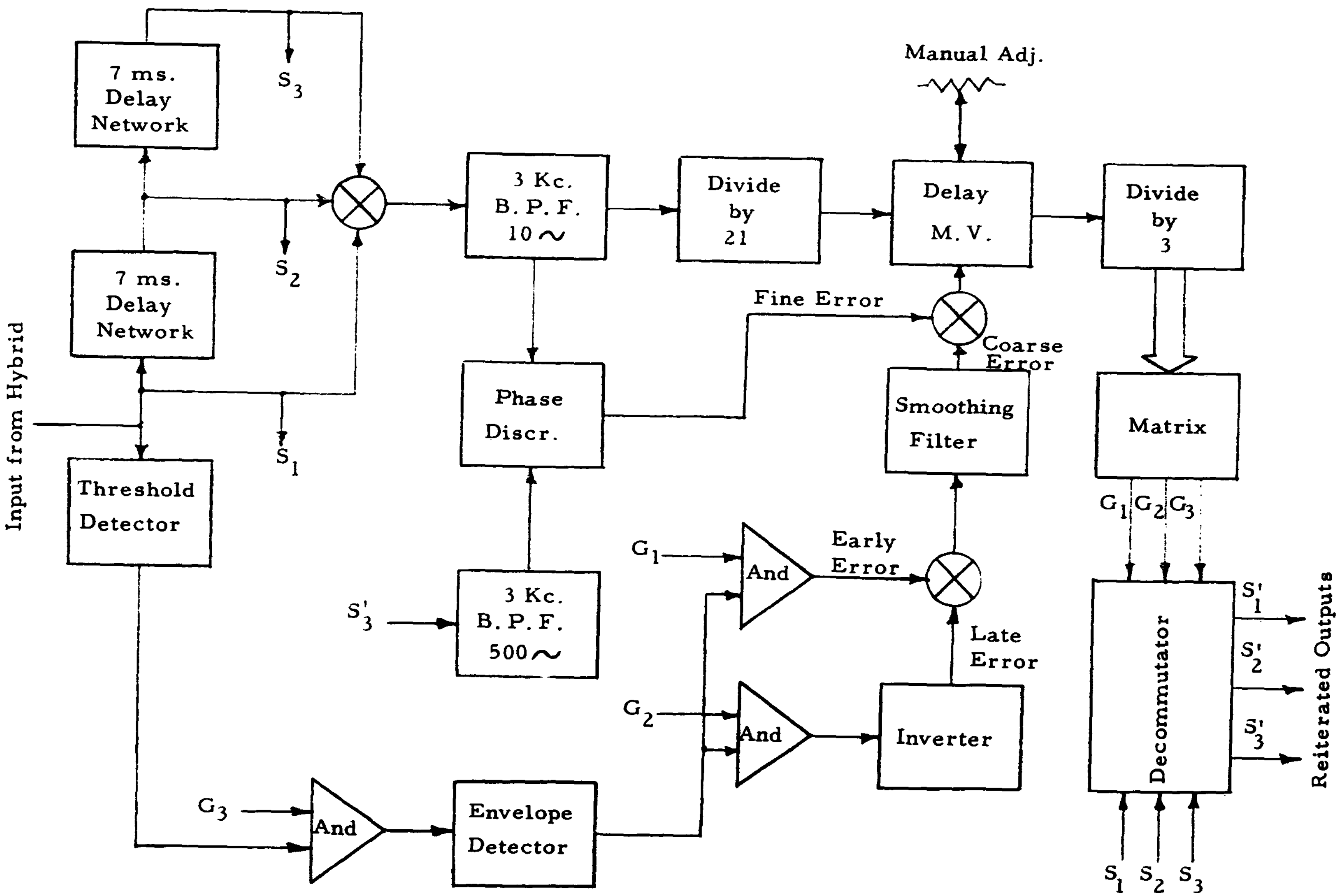


FIG. 15 IMPROVED SYNC DISCRIMINATION SYSTEM

Intelligibility and quality of reproduction are important factors in any voice communications link. The work done during the engineering investigation established the parameters for best intelligibility, however, without the aid of objective intelligibility testing through the use of PB words, nonsense syllables, and other accepted techniques. Time schedules prevented such tests being made on completion of the developmental models. Quality improvement was also studied in the engineering investigation and the work done there, especially in comb filtering techniques, supports the contention that much can be done to improve quality. These improvements were not included in the developmental models because they are beyond the scope of the contract. The synchronization problem also affected signal quality because of noise added from improper synchronization. Improvements in this area will have a significant effect on signal quality.

No work was done on the delay versus frequency problem encountered on long lines. Preliminary study of this problem indicates that it is of sufficient complexity that it should be the subject of a separate study effort.

2.4 Reliability

Economic considerations under this contract prevented the inclusion of a reliability program in work performed. MIL approved transistors were used in 97 percent of all transistor applications. Standard circuits were used wherever possible. No failures occurred in components because of inadequate design throughout the testing of the developmental models. As already pointed out, however, some of the system blocks are not as stable as they should be for optimum performance. Some suggestions have been made to improve these areas.

2.5 Maintainability

The developmental models delivered to RADC are basically research tools. It is anticipated that they will be used in further experimental work and as such maintenance will be dictated by the deterioration of components and units normally encountered in experimental procedures. Every effort has been made to provide easy access to individual circuits.

SECTION 3. CONCLUSIONS

The major conclusion reached on completion of the developmental demultiplexer-multiplexer equipments is that it is possible to build a practical reiterated speech system including the functions of synchronization and signaling. While the developmental models delivered to RADC were not without problems, the program has produced a wealth of knowledge on reiteration techniques heretofore unavailable. The conclusions reached at the end of the engineering investigation are still valid. The completion of the developmental models provided a complete system implementation of the techniques developed in that phase of the program. As pointed out in the discussion, synchronization was the major obstacle during the system test phase of the program. A workable sync system was achieved but study of the problem since delivery of the developmental models has produced a more satisfactory approach.

Preliminary study into applications for this type of equipment indicate a need for a digital approach to the problem. Aerospace communications systems for the future indicate a strong trend toward digital equipment for reliability, power conservation, and security. Also, a modest improvement in channel capacity at a low price is highly desirable for use with submarine cable facilities such as the Atlantic Missile Range, as well as on long distance tie lines.

SECTION 4. RECOMMENDATIONS

The conclusion of the work on the developmental models of the demultiplexer-multiplexer, while successful from the standpoint of demonstrating a working reiterated speech system, left several important problem areas either unstudied or unsolved. The results, however, are gratifying enough to recommend a continuation of work in this field. The two most significant areas requiring improvement in the present system concept are those of synchronization and the development of comb filtering techniques. A recommended approach to the synchronization problem has been discussed herein.

From application studies it is recommended that a digital approach be considered as an appropriate extension of this technique. For use of these techniques on long telephone lines, there still remains a problem of delay distortion as a function of frequency which has been given only a cursory examination. Finally, as an economic measure, the potential of frequency multiplexing to permit use of a single delay line to achieve multiple use of the line is recommended.

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